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THREE-DIMENSIONAL MORPHOLOGY OF THE SIGMOID NOTCH OF THE ULNA IN *KENYAPITHECUS* AND *PROCONSUL*

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ABSTRACT The three-dimensional (3-D) morphology of the sigmoid notch was examined in *Kenyanthropus*, *Proconsul*, and several living anthropoids by using an automatic 3-D digitizer. It was revealed that *Kenyanthropus* and *Proconsul* exhibit a very similar morphology of the distal region of the sigmoid notch; including the absence of a median keel and a downward sloped coronoid process. In addition, the proximal region of the sigmoid notch is curved more acutely relative to the distal region in *Proconsul*. This morphological complex is unique and not found in the examined living primates. The benefits of 3-D morphometrics are discussed.

Key Words: *Kenyanthropus*, *Proconsul*, sigmoid notch, three-dimensional morphometrics, ulna.

INTRODUCTION

Recently, automatic three-dimensional (3-D) digitizers have become more frequently to be used for biometrics. We introduced a 3-D digitizer using a laser beam scan, the Surveyor 500 (Matsuo Co., Saitama, Japan), to our laboratory for the purpose of analyzing tooth crown morphology. This digitizer is accurate enough to measure the location and shape of cusps, the course and depth of grooves, the development of the cingulum, and the size and orientation of worn facets (Ishida et al., 1994; Ishida and Shimizu, in press). In this short paper, we present an application of the 3-D digitizer to postcranial articular morphology. Articular shape is widely acknowledged as one of the best sources for inferring the positional behavior of extinct animals. Traditionally, the metrical analysis of articular shape has been mostly confined to linear lengths. While those measurements are conventional and practical, they exclude a part of morphological information if the articular shape is not better modeled as a geometrical entity such as a cylinder or sphere. Although the statistical treatment of 3-D configurations is still difficult, the 3-D digitizer is a powerful tool for clarifying basic patterns of morphologies and describing measurements that are important for characterizing different functional adaptations.

A proximal ulnar fragment of a presumably male *Kenyanthropus* is known from

Nachola, northern Kenya (Rose et al., 1996). This article reports the 3-D morphology of the articular surface of this material as well as several living anthropoids and Miocene hominoids. Some attempts are made to compare these 3-D configurations quantitatively.

MATERIALS AND METHODS

The materials include KNM-BG 17824 *Kenyapithecus* sp. from Nachola, KNM-RU 2036 CF *Proconsul heseloni*, KNM-RU 1784 *Proconsul nyanzae* from Rusinga Island, *Pan*, *Papio*, *Lophocebus*, *Presbytis*, and *Ateles*. The objects were molded by dark colored epoxy from the bones and museum casts for the purpose of this study. The Surveyor 500 (Matsuo Co.) was used to digitize the articular surfaces of the sigmoid notch. The Surveyor 500 has an ability to digitize 3-D coordinates within the errors of ± 0.05 mm along the XYZ axes. The scanning pitch was 0.2 mm in the XY plane. The entire articular surface of the sigmoid notch including marginal zones were digitized. Digitized 3-D configurations are shown in Figs. 1 and 2 in different orientations. For the purpose of obtaining 2-D profiles of the sigmoid notch, the 3-D configurations were cut by two planes (Figs. 3A, B). The section cut along the long axis of the sigmoid notch is shown in Fig. 4 with inscribed circles to the proximal and distal regions. The horizontal section is shown in Fig. 5.

RESULTS

Pan

The sigmoid notch of *Pan* is deep and directed proximoanteriorly (Fig. 4). The articular surface is divided into the lateral and medial surfaces by a median keel running throughout the notch (Figs. 1A, 2A). The median keel is slightly inclined proximolateral-to-distomedially with respect to the shaft axis. The keel starts from an anteriorly projecting beak of the olecranon ("olecranon beak") and runs distally to the tip of the coronoid process. The keel becomes sharper distally. The articular surface is moderately raised proximally along the sides of the olecranon beak (Fig. 1A, a). Medial to the median keel, the articular surface exhibits a mediolateral concavity (Fig. 2A, a). The surface is narrowest at the depth of the sigmoid notch and widest on the coronoid process. The articular surface on the lateral side of the median keel is narrower than the medial side. The lateral surface displays a convexity rather than a concavity along side of the olecranon beak (Fig. 1A, a) while the articular surface exhibits a mediolateral concavity on the coronoid process.

Papio

The sigmoid notch of *Papio* is as deep as that of *Pan*, but faces more anteriorly (Fig. 4) and lacks a median keel. The articular surface is more extensive proximally on the lateral side of the olecranon beak than on the medial side (Fig. 1A, b). The proximal region of the articular surface is directed distolaterally rather than distally. The articular surface is most narrow at the depth of the sigmoid notch. The coronoid is high and protrudes anteriorly (Fig. 1A, c). Almost the entire articular surface is beveled on the coronoid process so as to face proximomedially (Fig. 1A, c). This ar-

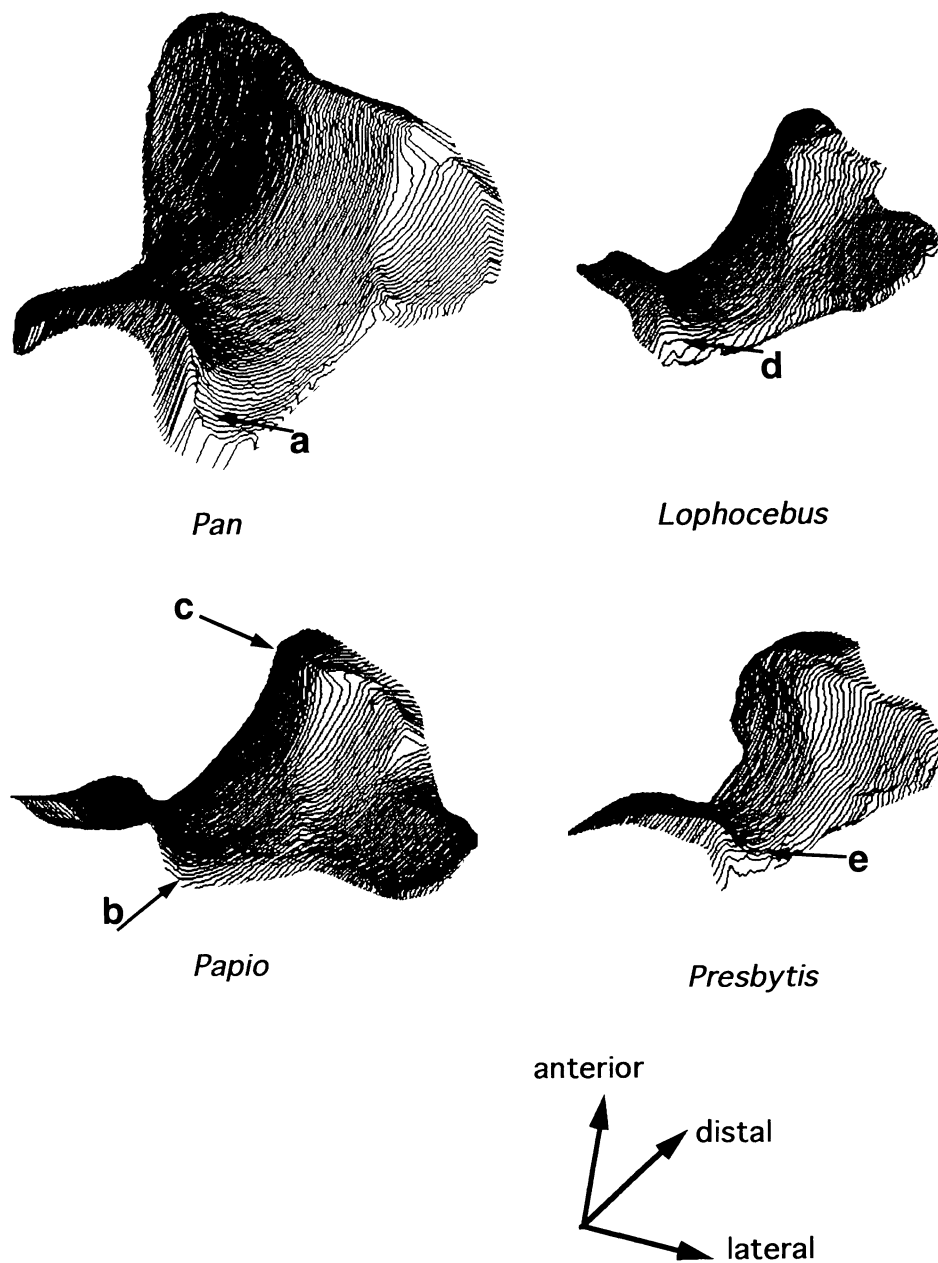


Figure 1. Digitized 3-D configurations of the right sigmoid notch seen from a proximolateral view point. A: *Pan*, *Papio*, *Lophocebus*, and *Presbytis*.

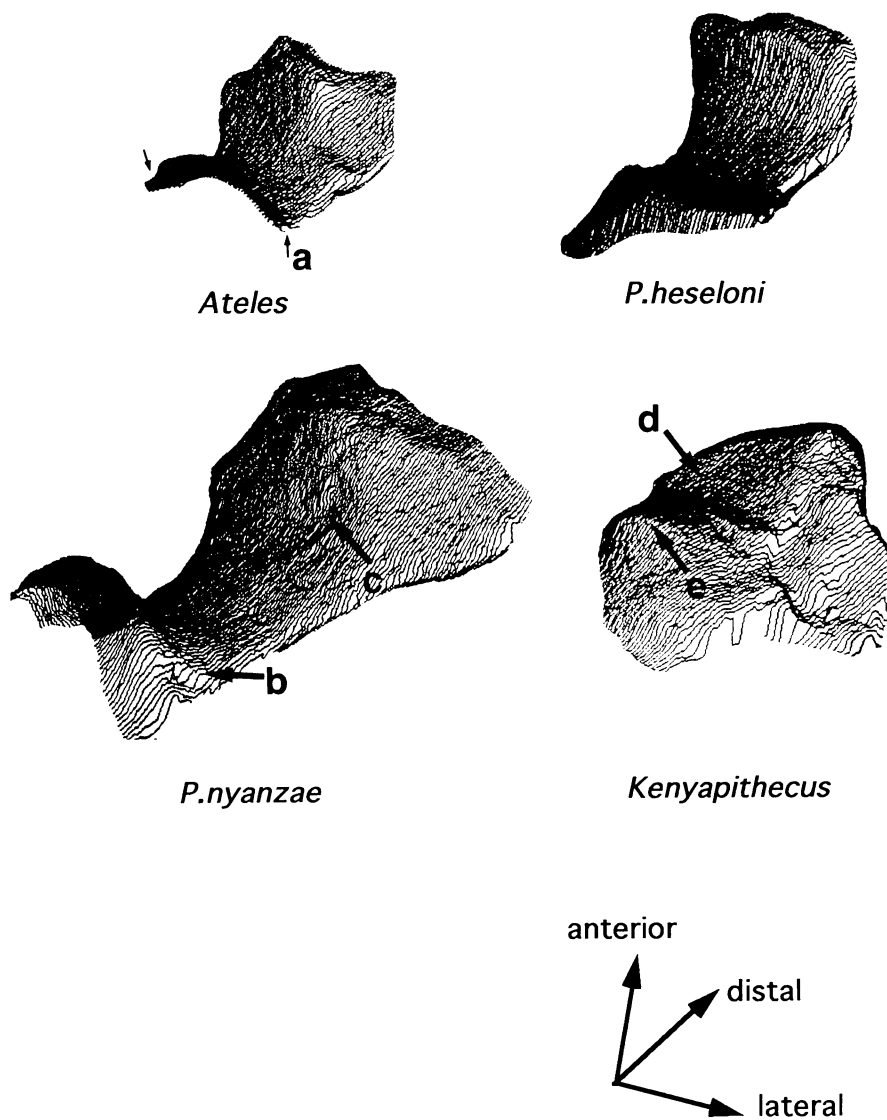


Figure 1. B: *Ateles*, *Proconsul nyanzae* (KNM-RU 1786), *P.heselsoni* (KNM-RU 2036 CF), and *Kenyapithecus* (KNM-BG 17824). The diagram of *P.nyanzae* is reversed for comparative purposes. The olecranon of *Kenyapithecus* is missing (e).

ticular shape is correlated with the humeral trochlea that is flanged medially on the anterior aspect (Rose, 1993). The proximolaterally and distomedially emphasized articular surface gives a “twisted” impression of the sigmoid notch, however, there is virtually no pitch angle of the humeroulnar joint, thus no translation of the ulna occurs mediolaterally during the flexion-extension (Rose, 1988).

Lophocebus

The sigmoid notch of the arboreal *Lophocebus* exhibits essentially a *Papio*-like “twisted” appearance, despite of their different strata preferences. However, *Lophocebus* differs from *Papio* in several ways. The sigmoid notch is shallower (Fig. 4). The proximolateral extension is more limited in the anteroposterior dimension (Fig. 1A, d). The coronoid process is narrower mediolaterally, hence the distomedial extension of the articular surface is less salient (Fig. 2A, b).

Presbytis

The sigmoid notch of *Presbytis* exhibits a less “twisted” condition with weaker articular extensions as compared with the above cercopithecines. However, basic morphologies are similar: laterally facing articular surface alongside the olecranon beak (Fig. 1A, e), absence of the median keel, and medially sloped coronoid (Fig. 2A, c). The proximolateral articular extension is limited to a same level as the proximomedial one. The coronoid process is reduced in height and the sigmoid notch is shallower than in the above cercopithecines (Fig. 4).

Ateles

The sigmoid notch of *Ateles* exhibits a unique combination of characteristics compared with *Pan* and the above cercopithecids. The sigmoid notch is very shallow with the reductions of the olecranon beak and coronoid process (Fig. 4). The sigmoid notch faces anteriorly and does not display a median keel. The articular surface as a whole is only weakly “twisted”. The proximal region of the articular surface is wide and does not extend on the sides of the olecranon beak proximally, displaying a mediolaterally symmetrical condition (Fig. 1B, a). The articular surface is only slightly narrowed at the depth of the sigmoid notch. The distal surface on the coronoid process is subtly sloped medially (Fig. 2B, a). This feature corresponds to the humeral trochlea that is sloped medially but not flanged like *Papio* (see above; also see Rose, 1993).

Proconsul nyanzae (KNM-RU 1786)

KNM-RU 1786 is a proximal ulna of adult *P. nyanzae*. Although the edge of the coronoid process is broken and the articular surface is somewhat weathered, it is well preserved. In side view, the proximal region of the sigmoid notch curves more acutely than the distal region (Fig. 4). Since the tip of the coronoid process is broken, the anterodistal extent of the sigmoid notch must be estimated. The distally directed coronoid projection (Figs. 1B, 2B, 4) suggests a shallow sigmoid notch that faces anteriorly rather than anteroproximally. The sigmoid notch is slightly “twisted”. There is a modest proximolateral articular extension which faces laterally along the lateral side of the olecranon (Fig. 1B, b). The proximomedial articular sur-

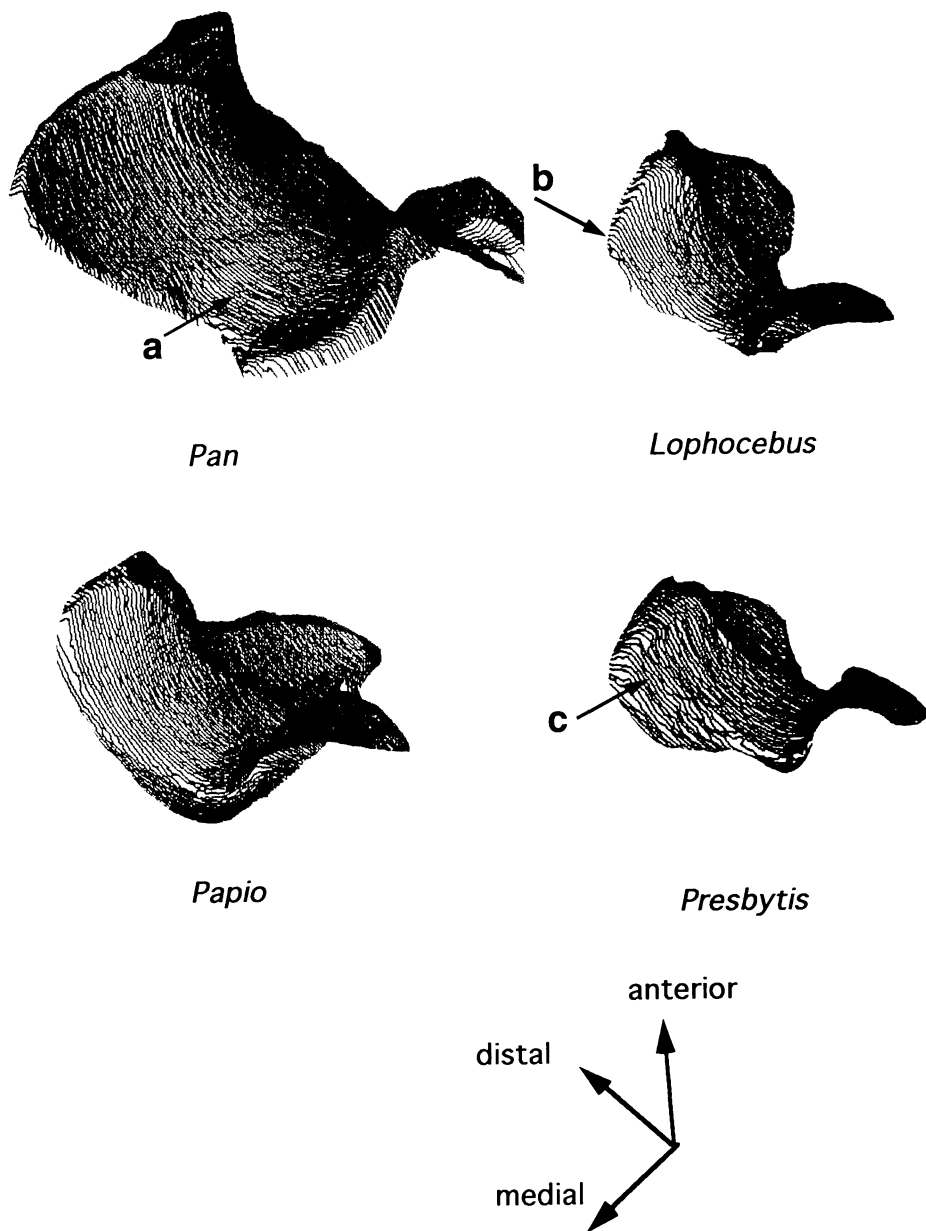


Figure 2. Digitized 3-D configurations of the right sigmoid notch seen from a proximomedial view point. A: *Pan*, *Papio*, *Lophocebus*, and *Presbytis*.

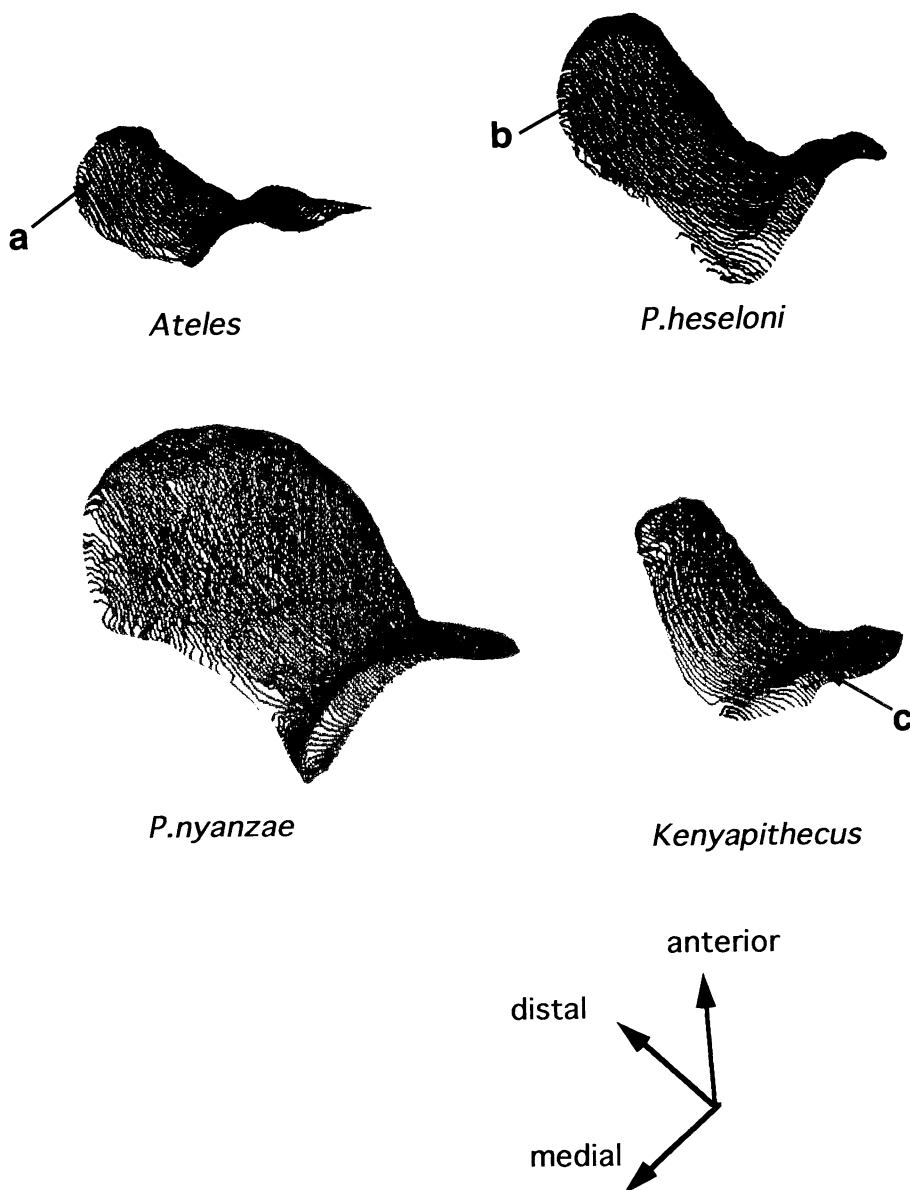


Figure 2. B: *Ateles*, *Proconsul nyanzae* (KNM-RU 1786), *P.heselsoni* (KNM-RU 2036 CF), and *Kenyapithecus* (KNM-BG 17824). The diagram of *P.nyanzae* is reversed for comparative purposes. The olecranon of *Kenyapithecus* is missing (c).

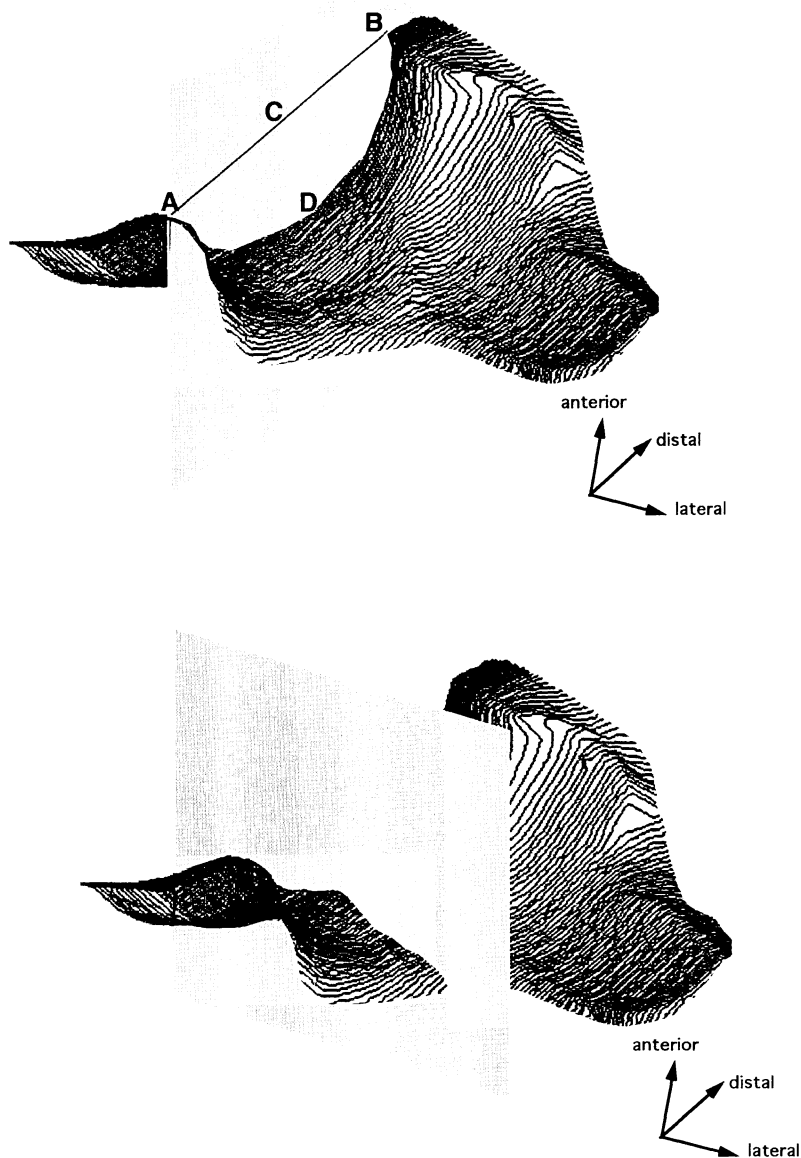


Figure 3. Digitized 3-D configurations of *Papio* ulna displaying the cutting planes by which sectional profiles were obtained. Upper: plane along the long axis of the sigmoid notch, lower: horizontal plane. Points A-D corresponds to those in the upper diagram of *Pan* in Fig. 4.

face extends as high as the lateral surface. The mid part of the articular surface is modestly narrowed. Mediolaterally this part is modestly convex (Fig. 5). The coronoid articular surface is mediolaterally broadened. Although the morphology of this articular surface, particularly the lateral part, is unclear due to the abrasion, the median keel is apparently not formed. However, the lateral marginal surface on the coronoid process is likely to be inclined laterally (Fig. 1B, c). The most part of the coronoid articular surface slopes slightly medially.

Proconsul heseloni (KNM-RU 2036 CF)

KNM-RU 2036 CF is a juvenile specimen of *P.heseloni*. The sigmoid notch is shallow and weakly “twisted”. In the side view, the proximal region of the notch has a curvature with a small radius while the distal region is slanted obtusely like *P.nyanzae* (Fig. 4). The proximal surface extends to the medial and lateral sides of the olecranon proximally to a modest degree. The bottom of the notch is modestly convex and somewhat keeled in the mediolateral direction but the median keel as is in *Pan* is not formed (Fig. 5; also see Napier and Davis, 1959). The coronoid process extends farther anteriorly than the olecranon beak, however, it is directed anterodistally rather than anteriorly (Fig. 4). The coronoid process is mediolaterally broad. The lateral border of the surface is slightly inclined laterally, but most of the surface is weakly medially slanted (Fig. 2B, b).

Kenyapithecus sp. (KNM-BG 17824)

KNM-BG 17824 lacks the olecranon and proximal part of the sigmoid notch. The coronoid process is abraded. Thus, the morphological information of the humeroulnar articulation inferred from this specimen is very limited. However, the articular surface on the coronoid process allows comparisons with other taxa confined to this area. In the side view, the coronoid process protrudes anterodistally drawing a weak curve (Fig. 4). Notably, its curvature and slope almost coincide with those of KNM-RU 1786 (Fig. 6A). If the proximal region of the sigmoid notch is reconstructed based on KNM-RU 1786, the sigmoid notch of this specimen becomes deeper and higher showing a shallower appearance compared with KNM-RU 1786 (Fig. 6B). At the proximal level, which seems to be the bottom of the sigmoid notch, the articular surface is only weakly convex in the mediolateral direction (Fig. 5) indicating the absence of the median keel. The coronoid articular surface is flat and inclined distally as well as medially (Fig. 1B, d).

DISCUSSION

The present analysis uses limited samples, hence intraspecific variation (size, age, sex) is not allocated for. Although further examinations are necessary, some hints of interspecific morphological variation of the sigmoid notch are clearly revealed.

Kenyapithecus and *Proconsul* exhibit a coronoid process that slopes distally drawing a weak curvature (Fig. 4; also see Preuschoft, 1973; Rose, 1983, this volume). Although the proximal region of the sigmoid notch of the *Kenyapithecus* specimen is missing, that of the two *Proconsul* specimens is more highly curved as compared

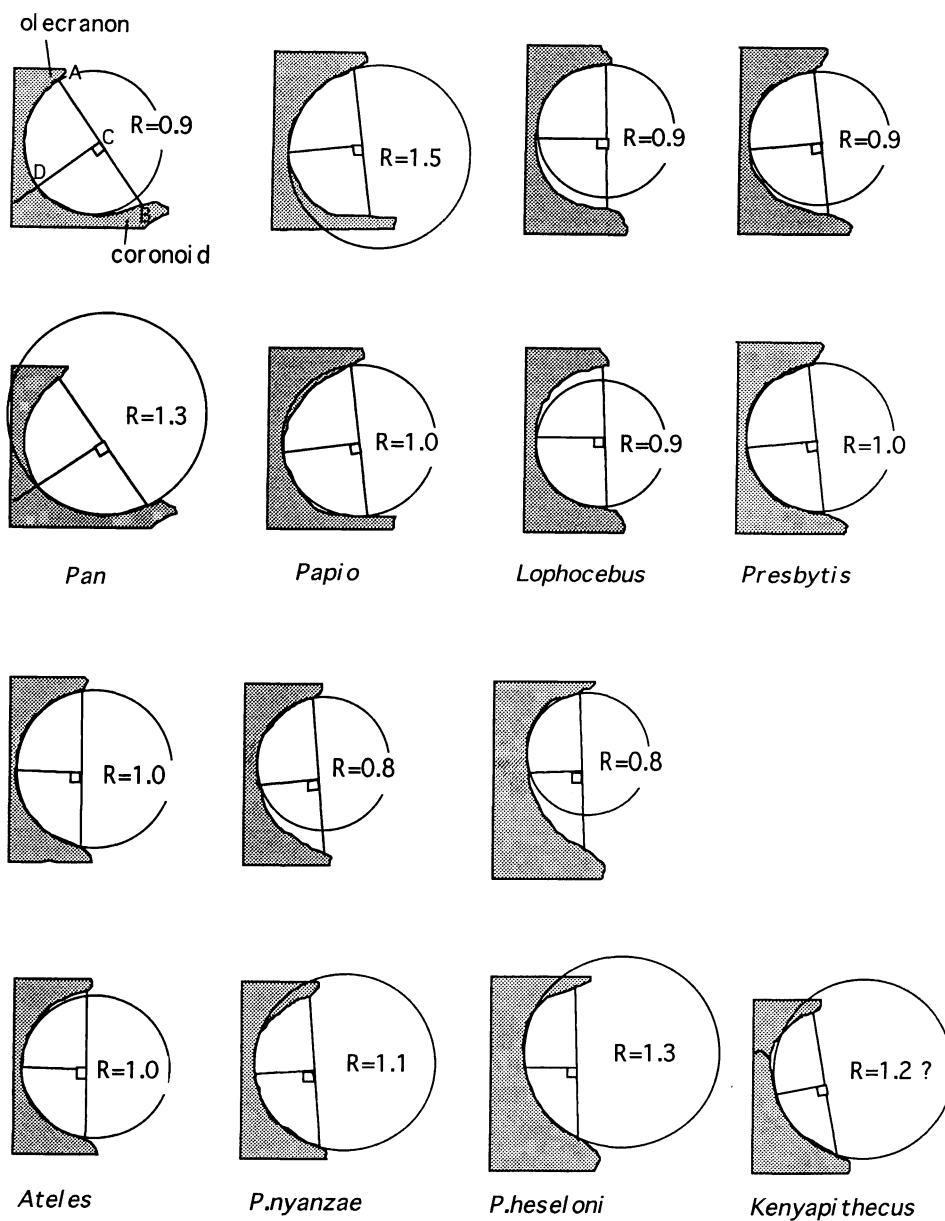


Figure 4. Profile of the sigmoid notch cut in the manner of Fig. 3. The scale is subjected to change to an equal length of the line AB. C is the midpoint of AB. The line CD is vertical to AB. The upper diagram shows a circle which fits with the arc AD, and the lower one that to the arc DB. The radius of the circle (R) is standardized by the length of AB. For restoration of *Kenyapithecus* ulna, see Fig. 6.

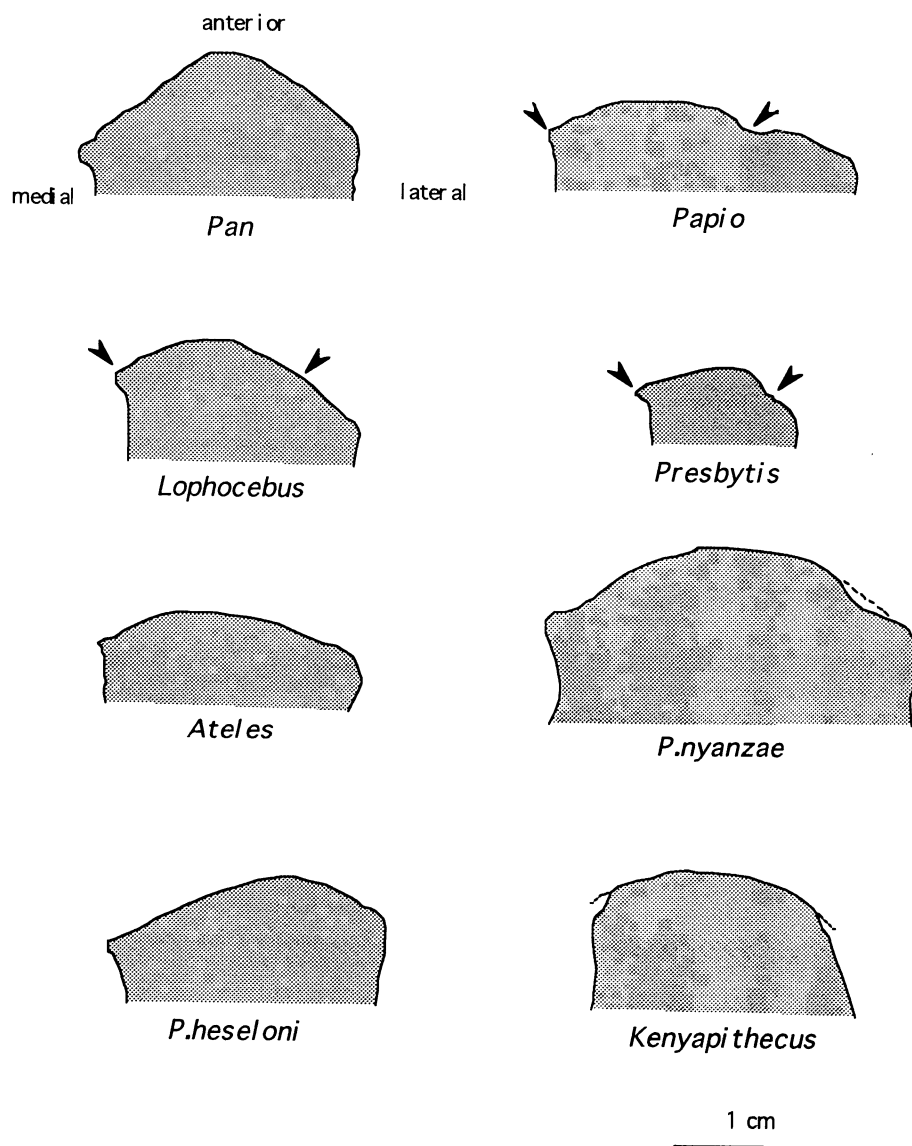


Figure 5. Horizontal section of the sigmoid notch at the mid level (Fig. 3). Arrowheads point to the margins of the articular surface.

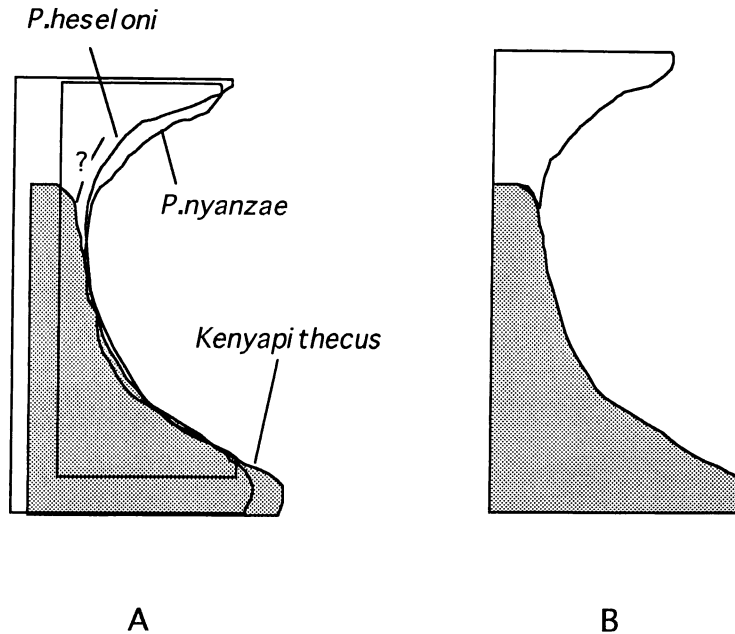


Figure 6. A: Profile of the sigmoid notch of *Kenyapithecus* and *Proconsul*. The scale is subjected to change to fit with each other. B: Reconstruction of the sigmoid notch of *Kenyapithecus* (KNM-BG 17824) based on the proximal region of the sigmoid notch in *P.nyanzae* (KNM-RU 1786).

with the distal region (Fig. 4). The close affinity of the distal region suggests that *Kenyapithecus* also has a similar type of the proximal curvature of the sigmoid notch. This pattern is peculiar in the examined living taxa except *Pan*. Most living taxa exhibit a similar or more weak curve in the proximal region relative to the distal region. While *Pan* also exhibits a relatively weak curve of the articular profile on the coronoid process, the coronoid protrudes anteriorly rather than anterodistally, differing from these Miocene apes. Morphologies of the sigmoid notch have been extensively studied (Conroy, 1976; Jolly, 1967; Knussman, 1967; Sarmiento, 1985; Rose, 1988, 1993). Conroy (1976) claimed that a more distally sloping coronoid process is indicative of an animal moving primarily with flexed elbow while an anteriorly directed coronoid indicates an extended elbow. The weak curvature of the coronoid articular surface combined with the distal slope will cause a less stable condition of the humeroulnar joint in a weakly flexed position (Fig. 7). The distal sloping of the coronoid in these Miocene apes is an indication of the elbow position with partial flexion (Preuschoft, 1973; Rose, 1983). On the other hand, the acute curvature of the proximal region of the sigmoid notch relative to the distal region (or vice versa) is not clear. A broader survey is necessary for a functional explanation of this character.

Proconsul and *Kenyapithecus* exhibit the incipient development of the median

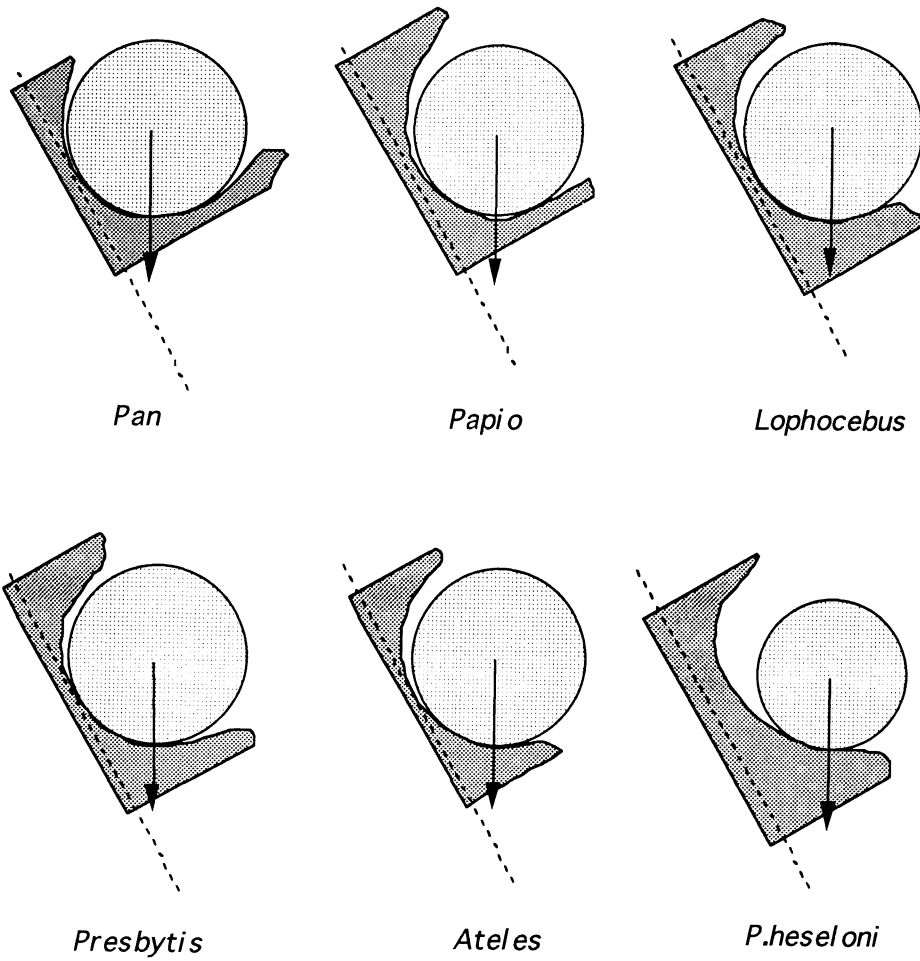


Figure 7. Diagram of the humeroulnar joint in partial (30°) flexion. The circle is scaled to the actual diameter of the humeral trochlea in each specimen.

keel of the sigmoid notch (Fig. 5; also see Rose, 1983, 1996). In the horizontal section of the sigmoid notch (Fig. 5), the articular surface is modestly convex in *P. nyanzae* and *Kenyapithecus*. *P. heseloni* displays a slight development of the median keel. In contrast, the median keel is very well developed in *Pan*. The keeled sigmoid notch provides the stability against rotatory torques throughout the full flexion and extension (Sarmiento, 1985; Rose, 1988, 1993). The trochlea of KNM-FT 2751 humerus from Fort Ternan, which is presumably attributed to *Kenyapithecus wickeri*, exhibits a weak concavity on the distal and anterior surfaces (Morbeck, 1983). The condition of the KNM-BG 17824 ulna corresponds to this morphology.

Computer aided 3-D morphometrics take time to measure, hence it is more limited in number of specimen it can conveniently examine than traditional osteometry. Although intraspecific variation is an important consideration, 3-D morphometrics enable precise comparisons to be made among a small number of specimens. Its merit lies in the ease with which conventional measurements, such as linear lengths, angles, radii of curvature, surface area, cross-sectional contour, volume *etc* can be obtained. It may also be applied to scaling and deformation of objects. Pattern matching techniques may enable articulated joint movements to be simulated. Although computer aided 3-D morphometrics will never replace traditional osteometry, it has a great potential as a supplementary tool in morphological studies.

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